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THE EVALUATION OF EXPERIMENTAL FABRICS AS ALTERNATES FOR STANDARD WOOL FABRICS

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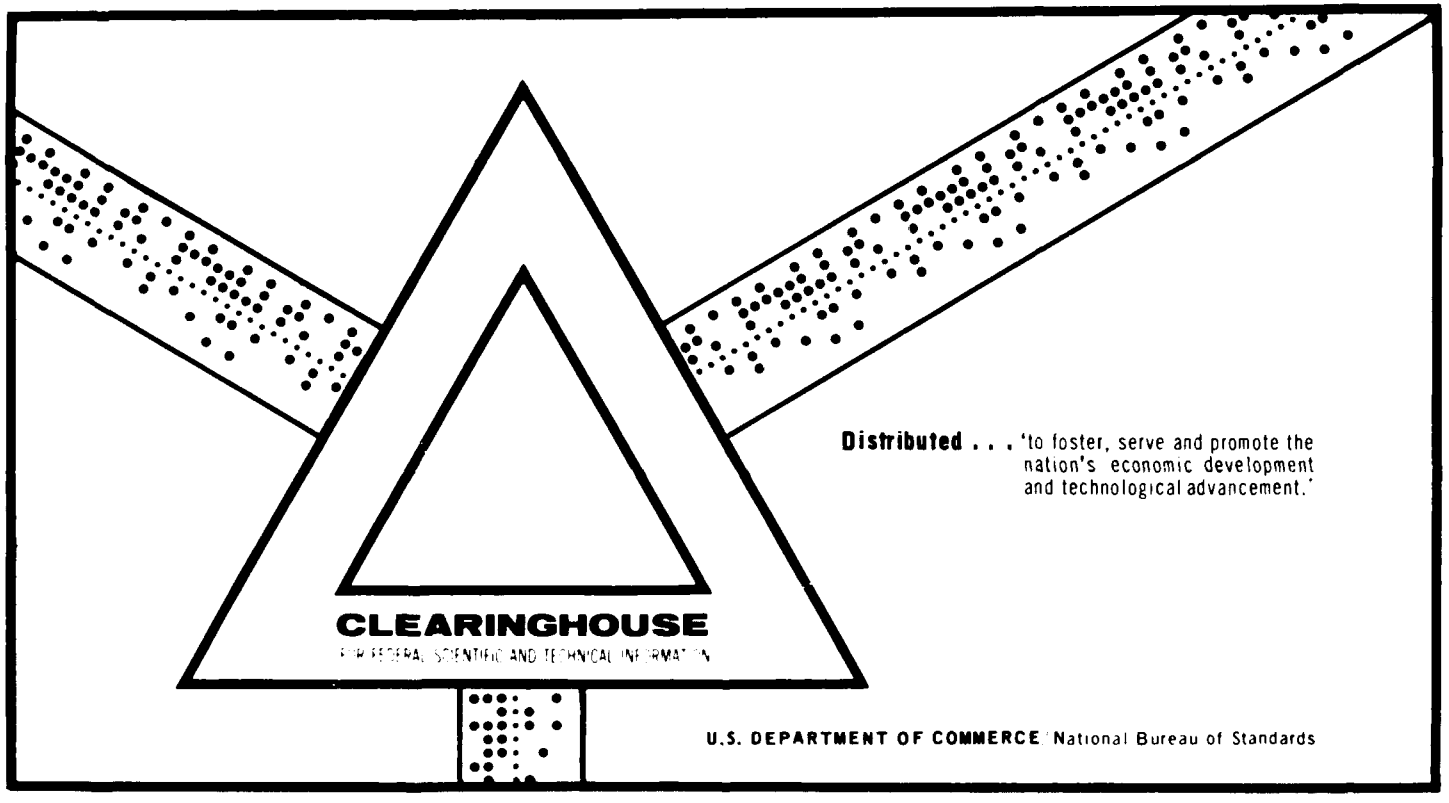

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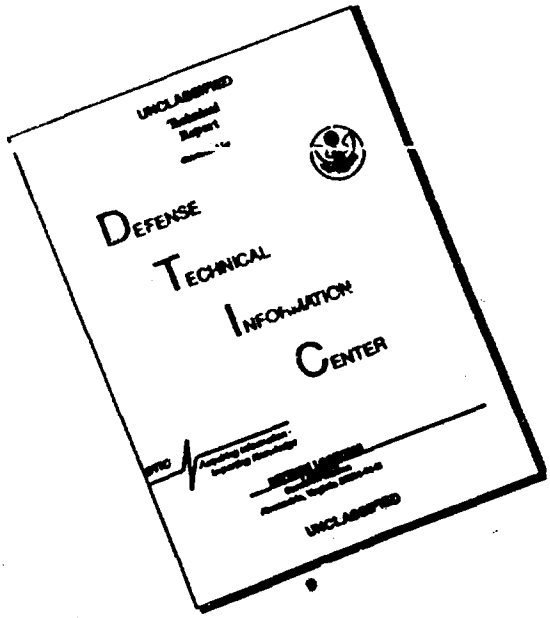

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Report No. 13

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THE EVALUATION OF EXPERIMENTAL FABRICS AS ALTERNATES FOR STANDARD WOOL FABRICS.

Contract No. DA-44-109-qm-564

Project No. 93-13-014, Development of Alternate Fabrics to Conserve Wool.

* * * *

SUMMARY

1. The effects of fiber denier and staple length on yarn diameter and fabric thickness of blends have been examined. Short staple fibers tend to favor the formation of short fuzzy surface fibers in blended yarns of wool with viscose, nylon, Dacron, and Dynel. These in turn give use to thicker yarns and more lofty fabrics than the longer staples. Increase in synthetic fiber denier in these blends using 2-1/2" staple tends to produce a greater number of long surface fibers and decrease the amount of closely entangled surface fuzz on the yarns. Apparently because of these opposing effects, no consistent trend in yarn diameter or fabric thickness was observed on change in denier in the constructions used.

2. An examination of the thermal resistance of several four layer cold weather assemblies by the cold wind tunnel technique, shows that moisture introduced into the assembly by a sweating cell may lower the insulation by as much as 35%. For a cell cooled in a wind stream at 12 mph and -5° C., this corresponds to a shortening of the time required to cool the "skin" to 15°C. from 20 to 12 minutes. Although the thermal resistance of such a moist assembly in cold exposure is largely determined by its thickness, the concentration of moisture in any one layer may lead to an increased loss in insulation. Fabric surface hairiness, wettability, and water holding capacity all appear to have some effect on the amount of moisture transferred between layers and hence on the overall moisture distribution and thermal insulation. However, on the assemblies that have been examined, the changes in insulation due to these effects do not appear to be large. The influence of moisture is most pronounced if the thickest of the insulating layers of the assembly is involved. Situations are possible in which some of the advantages normally realized by using thick, fuzzy fabrics in dry thermal insulation are offset by an increased tendency for moisture to collect in these particular components of the assembly.

3. A relatively simple method for comparing the comfort value of experimental shirts on human subjects has been evaluated. Test trials on a limited number of subjects gave results which appear to correlate well with laboratory findings and with general experience. The method is based on determinations of the rate of cooling of the fingers of subjects clothed in various ways and subjected to a chilling stress for a short period. It appears that the most useful results are obtained from examination of cooling curves of the same subject in successive experiments clothed in garments under comparison. The

trials also showed that finger temperature decrease corresponded well with subjective feelings of chill and discomfort described by the individuals' participating. This technique, therefore, appears to be of interest for further testing with the goal of providing a relatively simple means for physiological verification of laboratory findings.

DETAILS

I. The Thickness and Surface Properties of Blended Fabrics in Relation to Yarn Construction Features

A. Introduction

Studies of the thickness and surface properties of blended fabrics rich in synthetic fiber content and made by conventional procedure have shown that they tend to be smooth and lean. At the same time, the value of using thick, lofty fabrics for protection in cold weather garment assemblies has been well demonstrated. The methods by which greater thickness and loft may be enhanced in blended fabrics still remain to be explored.

It has been shown that fiber alignment in the fabric yarns plays an important role in determining the thermal and wetting properties of blended fabrics. In the present studies, the influence of staple length and fiber size on fiber alignment in the yarns and on fabric thickness is examined for several blended fabrics.

B. Experimental

A series of experimental yarns and fabrics was prepared at the Philadelphia Textile Institute from fibers differing in denier, staple length and chemical construction. Blend series containing a) 100% wool, b) 2/3 synthetic-1/3 wool, and c) all synthetic were made using viscose, nylon, Dacron and Dynel. The yarns were specified to be spun alternatively on the cotton or woolen system, to a nominal count of 14/2 (cotton equivalent) with a singles twist of 10 tpi and ply twist of 8 tpi. Fabrics were woven from these yarns in a 2/2 twill weave with a 68 x 56 texture specified, corresponding to Army serge construction. Relaxed samples were used in the present study.

Samples were taken from the spools of yarn at 20 yard intervals and mounted under slight tension on cardboard frames. Photographs of the yarns were taken against a white background and enlarged prints of these were prepared for examination. Yarn diameter and the number of short and long surface fibers were estimated from the photographs.

Thicknesses of the fabrics under applied pressure from 0.002 to 2.0 lbs/in^2 were obtained with a Schiefer compressometer.

C. Effect of Staple Length

The result of using 1" and 2-1/2" staple in the experimental yarns and fabrics is seen in Table 1. For the all wool fabrics the use of the shorter staple length produced an appreciably thicker fabric at all the pressures studied, and this behavior is directly reflected in the appearance of the yarns. The yarns made from 1" staple were approximately 25% thicker than those from 2-1/2" staple and this appeared to be due mainly to a difference in the number of fibers close to the surface.

For the blends containing two-thirds synthetic fiber, the effect of change in staple length on yarn diameter and fabric thickness was similar to that for the all wool materials but not as pronounced. Again, the significantly greater fabric thickness with the short staple appeared to be due to a change in the number of fibers near the surface, although there appeared to be a number of long surface fibers (5X yarn diameter) in all of these yarns.

For the yarns and fabrics of all nylon and all Dacron there was no appreciable change in the fabric thickness with change in staple length in spite of the fact that there was some change in the number of long surface fibers. It would appear from the examination of this series that it is the

small numerous fuzzy fibers close to the surface, so prominent in the all wool samples, which give rise to the increase in thickness.

D. Effect of Denier

Some comparisons were available among yarns made from 2-1/2" staple which differed only in the denier of the synthetic used. The results of the examination were rather conflicting in terms of the effects produced by denier changes. In general, the use of larger denier synthetics (5 or 6 denier in place of 3 denier) led to yarns which were hairier in respect to the long, sparsely-distributed surface fibers but these frequently exhibited fewer short fibers at the surface. These effects appeared to cancel each other in that, for fabrics made from these yarns, no consistent trend in thickness was observed as a function of denier. In addition, the blended yarns made with 2-1/2" staple fiber were rather lean in this construction, the fibers being effectively bound into the yarn structure. Accordingly, the expected effects of denier may have been obscured by this type of fiber interaction.

These samples are being examined further for evaluation of the role of fiber denier.

E. The Effect of Blend and Fiber Type

Changes in yarn diameter and fabric thickness were studied as a function of the amount of nylon and Dacron blended with wool, and the results are summarized in Table 2. Using 1" staple, the yarn diameters and fabric thicknesses for the 2/3:1/3 blends lay somewhere between high values for the wool and low values for the all synthetic. The all wool yarns appeared to be fuzzier and thicker than the others because of a great number of the short intertangled surface fibers. On the other hand, the all nylon yarns seemed to be thicker than the all Dacron yarns by virtue of having more of the long surface fibers.

For the series using 2-1/2" staple the effects of blend and fiber type were similar to these for 1" staple but not as pronounced. In general, the yarns and fabrics with 2/3 synthetic fiber tended to be very like the ones containing 100% synthetic fiber.

F. Conclusions

1. For the yarns and fabrics of the present series, it appears that the thickness and loftiness of the fabrics is directly related to the hairiness and diameter of the fabric yarns.

2. Yarn diameter and fabric thickness are appreciably increased in going from 2-1/2" to 1" staple for this experimental series.

3. Increase in fiber denier from 3 to 5 or 6 has only a small effect on yarn and fabric thickness in the present fabrics.

4. The effects observed appear to be related to the existence of two distinct classes of surface fibers in these blends: a) a short fuzzy type in which many entangled fibers extend only a short distance from the surface; these were most characteristic of the wool yarns studied; b) a long, widely spaced type extending several yarn diameters beyond the surface, typified by the all synthetic yarns studied, particularly those with crimped fibers. The surface fibers of type a) appear to be most effective in increasing yarn diameter and hence fabric thickness, and their existence is most favored by the use of short staple fibers and wool-rich blends.

II. Cooling Studies in a Cold Wind Tunnel

A. Introduction

For evaluation of the insulating properties of cold weather garment assemblies, a new experimental cooling method has been developed (Report 11).

The experimental technique is based on the cooling of a clad metal cell in a cold wind tunnel, and the rate of cooling is related to the thermal insulation of the assembly with which the cell is clad. It has been shown that if S is the surface area, C_p is the heat capacity of the metal cell, and m_o is the slope of the logarithmic cooling curve for heat losses through the insulated ends of the cell, then the overall thermal resistance of the assembly on the cell is

$$R_T = -S/2.303\ C_p\ (m-m_o), \qquad (1)$$

in which m is the slope of a logarithmic cooling curve for the cell.

Considerable attention has been given to the construction of an instrument which simulates as closely as possible actual body heat and moisture relations. In the present work, the cell acts to duplicate the stress met by a man who is working hard and sweating and then suddenly made to lie still in the cold. The ways in which various cold weather assemblies modify this type of chilling form the material for the present study. Thus this work involves a consideration of insulation properties of clothing under cold conditions, in which moisture is introduced by perspiration.

B. Experimental

In order to simulate conditions of sweating, a chamois sleeve was placed over the cell of the previous apparatus (Report 11). Fabrics under test were wrapped around the wet chamois and the assembly placed in the cold wind tunnel. Wind velocity and temperature were 11.7 mph and -5°C. in these experiments. The skin of the cell was held at 30°C. for a predetermined "equilibration" time, then the cell heat output was lowered to a new low value and the cell allowed to cool. Heat output of the cell (corresponding to metabolic rate in the human analogy) was 680 $Cal/m^2/hr$ before cooling and 62 $Cal/m^2/hr$ during cooling.

Cooling curves were plotted as in previous runs with dry assemblies and the overall thermal resistances calculated using equation (1). As a practical measure of the insulating ability of each assembly, the time required for the "skin" to cool to the physiologically low temperature of 15°C. was also obtained. This was called the Exposure Time, t_{15}, as in previous cold wind tunnel studies.

C. Insulation Losses Due to Moisture in a Fabric Assembly

It was observed that moisture from the wet skin of the sweating cell, distributed through a four layer cold weather assembly during equilibration, had a marked effect on the subsequent cooling rate of the cell. Changes in thermal resistance with added moisture as a function of the length of the equilibration period are given for one of these assemblies in Figure 1. This was a standard assembly containing 50/50 wool/cotton underwear, an all Orlon serge, and a field jacket of oxford with sateen shell.

The decrease in thermal resistance with increase in equilibration time seemed to reach a maximum after about an hour and for most of the assemblies studied amounted to an overall insulation loss of about 35%. As can be seen by comparison with previous studies on dry assemblies (the arrow in Figure 1 shows resistance level of dry 2 layer assembly) this was more than the loss that would be sustained by removal of the field jacket. Stated in another way, introduction of moisture into the assembly reduced the Exposure Time, t_{15}, from 20 to 12 minutes. A similar lowering was observed for all the four layer assemblies studied.

In the previous cooling studies on dry assemblies, it was shown that

the second layer consisting of trouser or shirting material was the main insulating layer of such a cold weather assembly. In addition, it was shown that the overall thermal resistance of the dry assembly was determined mainly by total thickness. The results of cooling studies on several four layer assemblies exposed to heavy sweating conditions for 37 minutes are given in Table 3. These assemblies differed in the fabric material of the second layer, and it is seen that in general for the thicker assemblies, better insulation was achieved. Measurement of the surface temperatures of the fabrics during a cooling experiment, using the wire grid method (Report 12, page 9), showed that most of the temperature drop occurred across the second layer. The thermal gradient was appreciably greater across the thicker wool fabric (17) than across the thinner Orlon serge (20) in all the cases examined.

A closer examination of the overall thermal resistances of the assemblies of Table 3 shows that insulation is not simply related to total thickness. In seeking to determine other factors which might affect the overall resistance, the contrasting appearance of the serge fabrics after a run suggested that the distribution of water might be of importance. For example, the fabrics of Orlon were visibly wet with liquid water on the surface and these assemblies exhibited lower resistance. Since previous work had shown that surface wetness and smoothness of fabrics influenced the rate of water transfer between layers, further cold wind tunnel experiments were carried out using fabrics of different surface properties but comparable thickness.

D. Moisture Distribution Effects

Cooling experiments were carried out on three cold weather assemblies using an Orlon serge, a wettable wool serge, and a sheared wool serge for the

second layer. After each cooling run, the fabric layers of each assembly were separated and weighed, and thus the final distribution of moisture in the assemblies could be obtained. Cooling runs were carried out for equilibration times of 25 and 40 minutes and the results are summarized in Table 4.

The serge layers of these assemblies differed in two major respects. The Orlon serge was wettable and smooth, the first wool serge was wettable and hairy, while the sheared wool serge was neither wettable nor smooth. The distribution of moisture in the various layers of the assemblies was quite different in each case.

The more readily wettable wool and Orlon fabrics appeared to facilitate transpiration of moisture to the outer field jacket in that weight increases of 15-30% were observed in the oxford layer, depending on the equilibration conditions. However, the overall thermal resistances of these assemblies were quite different. Conversely, although the thermal resistances of the assemblies containing Orlon or sheared wool serges were similar, the moisture gained by the outer layers of these assemblies was quite different. Apparently differences in the moisture content of the relatively thin outer layers of such assemblies influence the total resistance to only a minor extent.

The moisture distribution in the thicker underwear and serge layers of these assemblies also differs. While assemblies containing Orlon or sheared wool differ in the way in which water is distributed in the first two layers, the moisture contents lie near a mean value of 37%, which is considerably above the mean value of 31% obtained for the assembly containing wettable wool serge. These differences in moisture content are reflected in the thermal resistance values, the values for the assembly with wettable wool serge being

above the others. Apparently concentration of most of the moisture in either inner layer can lead to a lower thermal insulation value for that assembly.

These results suggest that concentration of moisture in the inner insulating layers of an assembly which is favored by the use of hairy non-wettable serge fabrics may counteract the advantage possible from the fact that such fabrics are normally thick and lofty. This might explain why the assembly containing a thick shirting in Table 3 did not show a higher overall thermal resistance as would be expected. It should be possible to check this postulate by experiments on assemblies containing a water impermeable or semi-impermeable layer placed between inner and outer layers of the assembly. The relation of this work to the "Va-bar" principle of cold weather clothing should be most useful, and these experiments are now under consideration.

Another series of cooling experiments was carried out on a group of thinner four layer assemblies in which both the underwear and serge types were altered. The results of this work are given in Table 5. Assemblies containing wettable and non-wettable nylon underwear with both the Orlon and the sheared wool serge of Table 4 were used.

The distribution of moisture in the fabrics of these assemblies was strikingly different. In general, the use of water-repellent underwear decreased the transfer of moisture to the outer layers, and the transfer of moisture to the oxford fabric from the smooth, wettable Orlon serge was greater than from the hairy, non-wettable wool serge in both cases considered.

Differences in thermal resistance of the assemblies with Orlon or with wool serge were also obtained. These seem to have resulted partly from differences in thickness of the serges and partly from differences in the water

content of the oxford layer. With such thin assemblies, every component makes a bigger contribution to the insulation. Accordingly, for the relatively thin assemblies containing Orlon serge, the high concentration of water in the oxford layer could, therefore, contribute to lowering the thermal resistance in these cases.

The assemblies containing water repellent nylon underwear (65) are both thinner and less moist than the similar assemblies containing wettable nylon underwear (62), and, in terms of thermal insulation, these effects about balance one another, for the corresponding assemblies of each set have about the same overall resistance. Accordingly, alteration of the type of underwear of these assemblies is apparently thermally equivalent to a small change in total thickness.

E. Conclusions and Discussion

These cold wind tunnel studies have shown that the moisture which penetrates a four layer cold weather assembly from a sweating cell can materially lower the thermal insulation of the assembly. In general, thicker assemblies provide better insulation, but this depends somewhat on which fabric layer collects the moisture. It is shown that variations in the fabric type of a component of an assembly can alter the distribution of moisture in the assembly. This appears to affect the insulative protection most when the moisture concentrates in those fabric layers contributing the most to the overall resistance. In this way, the extra warmth usually realized by employing thick, lofty fabrics as insulating layers may be partially offset by the presence of moisture.

Experiments with six layer cold weather assemblies containing friezes are proposed for studying this problem in a system in which one layer provides

most of the effective insulation. It will be of considerable interest to determine how moisture transfer to the frieze layer is affected by the nature of adjoining layers and what effect this has on the overall thermal resistance of such an assembly.

III. Chilling Experiments on Subjects

A. Introduction

Although the evaluation of blended fabrics in terms of comfort properties must depend on thermal measurements in the laboratory, the ultimate comparison must depend on actual subjective tests under practical conditions. Investigations of the physiology of comfort by workers in the medical field is of appreciable help in selecting the right attributes for study in the laboratory and, indeed, the technique devised for cooling experiments given in the previous section was based on just such considerations.

In an attempt to relate these laboratory studies to actual experience, chilling studies were carried out with subjects under controlled conditions and the present account is an evaluation of the method which was proposed for this purpose.

B. Principles of the Method

Studies of the changes in physiological function of humans subjected to a cooling stress have shown that change in temperature of the extremities is closely related to the intensity of such a stress. Accordingly, a method was devised for measuring the finger temperatures of subjects clothed in different ways and exposed to a chilling temperature in a wind stream. Considerable care was exercised to control the metabolic activity of the subjects before, and during, the course of a chilling experiment.

C. Experimental Procedure

Temperature sensitive elements of nickel wire were prepared for measuring the inner and outer sleeve temperature of a series of experimental shirts and for measuring the finger temperatures of subjects wearing these shirts. Temperatures were obtained from the readings of a Kelvin Bridge used to measure the electrical resistance of each element. These were connected in such a way that four subjects could be examined continuously throughout the course of a chilling experiment.

In the present experiments, subjects were clothed in standard Army underwear and trousers and asked to wear one of three types of experimental shirts, an all wool, a napped wool, or an all Orlon sample. Long wool socks were worn to prevent chilling of the legs which was found to be an interfering factor in preliminary experiments.

Chilling was carried out in a cold room held at 60°F. and a relative humidity of 56%. Subjects lay on cots and were asked to relax but not talk during the course of an experiment. Reading was permitted. The inside and outside sleeve temperatures, as well as finger temperatures, were taken on each subject at roughly five minute intervals during the course of a two hour chilling run.

Four male subjects between the ages of 25 and 28 were used in this series of experiments. Two wearing the wool and napped wool shirts were allowed to rest in the cold room but covered with blankets for a half hour before chilling was begun. It was found that this type of conditioning brought the subjects to approximately the same metabolic level in successive experiments. The other two subjects wearing Orlon and wool shirts

respectively, were subjected to moderate exercise for ten minutes prior to entering the cold room for a chilling run. The procedure was designed to make the subjects perspire and so begin the cooling run with some added moisture in their clothing. All four subjects were asked to record their reactions towards chilling as the run proceeded. Shirts and positions of the subjects were rotated on successive days of the experiments and runs carried out between 9:30 A.M. and noon every day to avoid the complicating factors of meals. The temperature measurements were made by an operator and subjects were kept from knowing their cooling behavior as the run proceeded.

D. Results

It was observed that the changes in finger temperature with time were directly related to the subjective cold feeling of the subjects. Any precipitous drop in temperature was usually felt by the subject and recorded on his chart. It was also observed that small changes in finger temperature could be correlated with changes in activity of the subject; for example, in a change from reading to resting, but these changes were generally not related to the overall rate of cooling of the subject.

A comparison of the cooling curves for subjects wearing the same shirt showed that their individual response to chilling varied over quite a wide range. Smoothed cooling curves of this type are given in Figures 2a and 2b. It was concluded from the wide subject-to-subject variability that it would be necessary to make shirt comparisons on the same subject.

From the available cooling data, cooling curves were selected in which the same subject wore the same shirt in two successive experiments. Sets of these are given in Figures 3a and 3b. The close agreement in the response of

each subject to the same cooling stress was encouraging with respect to the reproducibility of the method and to its sensitivity. This was true for runs in which the subjects were conditioned at rest (3a) and for runs in which the subjects were exercised before cooling (3b). However, in the latter case, there was some complication in the cooling curve due to a carry over of the high metabolic activity of the subject into the cooling run. This prevented a direct comparison of cooling curves in dry and moist cases but still made it possible to compare several wet cases with one another. The technique could be improved appreciably if the subjects wearing moisture laden fabrics were also pre-equilibrated in the cold before commencement of a cooling run.

A comparison of the cooling rates for different shirts on the same subject can be made from the curves of Figures 4a and 4b. In Figure 4a, it is seen that the cooling curve for the subject wearing the moist wool shirt lies appreciably above that for the same subject wearing a moist Orlon shirt. These differences lie in a sensible direction in terms of the thicknesses of these materials and agree with those found for similar materials in cold wind tunnel studies. In Figure 4b are curves for a subject wearing a napped shirt and a wool shirt control. These cooling curves also seem to differ in a sensible way, the curve for the thick napped fabric being above that for the wool control. From a comparison with the curves of Figure 3, it would appear that these differences are probably significant in this type of experiment.

The general conclusion that can be drawn from this series of chilling experiments using human subjects is that this technique may be useful for checking the results from laboratory studies on fabrics. This may then provide a relatively simple way in which to relate laboratory data of the type discussed in Section II with actual feelings of physiological comfort.

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Table 1, Report 13

The Effect of Blend and Staple Length on Yarn[a] Hairiness and Fabric[b] Thickness

Sample Number	Blend Composition[c]	Staple Length in	Relative Yarn Diameter wool, 1 inch staple = 1	Yarn Surface Fibers		Fabric Thickness in mils at		
				Short	Long[d]	0.002 lbs/in^2	0.01 lbs/in^2	2.0 lb/in^2
404	100% wool	1	1.0	great many	few	115	93	55
413	100% wool	2-1/2	.8	many	few	94	77	39
406	2/3 viscose, 1/3 wool	1	.8	many	some	86	71	36
415	2/3 viscose, 1/3 wool	2-1/2	.5	some	some	80	66	33
410	2/3 Dacron, 1/3 wool	1	.8	many	some	89	69	35
421	2/3 Dacron, 1/3 wool	2-1/2	.5	few	some	82	59	30
412	2/3 Dynel, 1/3 wool	1	-	-	-	90	70	38
423	2/3 Dynel, 1/3 wool	2-1/2	-	-	-	81	64	32
407	100% nylon	1	.8	some	many	94	69	37
416	100% nylon	2-1/2	.6	few	some	92	65	36
409	100% Dacron	1	.6	few	some	73	53	30
420	100% Dacron	2-1/2	.5	few	many	75	53	29

a Yarns are nominally 14/2, cotton count equivalent, singles twist 10 tpi, ply twist 8 tpi.
b Fabrics are loomstate, weave 2/2 twill, 68 picks x 56 ends (nominal).
c Wool fibers are 62-64's, other fibers are 3 denier, all synthetics crimped except viscose.
d Relative yarn diameters and the number of surface fibers are taken from yarn photographs.

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Table 2, Report 13

The Effect of Blend and Fiber Type on Yarn Hairiness and Fabric Thickness

Sample Number	Blend Composition	Relative Yarn Diameter wool, 1" staple = 1	Yarn Surface Fibers		Fabric Thickness in mils at		
			Short	Long	0.002 lbs/in^2	0.01 lbs/in^2	2.0 lbs/in^2
			1 inch Staple Length				
407	100% nylon	.8	some	many	94	69	37
408	2/3 nylon, 1/3 wool	.8	many	some	96	73	38
404	100% wool	1.0	great many	few	115	98	55
410	2/3 Dacron, 1/3 wool	.8	many	some	89	69	35
409	100% Dacron	.6	few	some	73	53	30
			2-1/2 inch Staple Length				
416	100% nylon	.6	few	some	92	65	36
417	2/3 nylon, 1/3 wool	.6	some	some	91	68	35
413	100% wool	.8	many	few	94	77	39
421	2/3 Dacron, 1/3 wool	.5	few	some	82	59	30
420	100%	.5	few	many	75	53	29

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Table 3, Report 13

The Overall Thermal Resistance and Exposure Time of Several Wet Cold-Weather Assemblies, Wind Velocity 11.7 mph, Initial Temperature 30°C., Equilibration Time 37 min.

Fabric Assembly[a] Second Layer	Assembly Thickness at 0.01 lbs/in^2 mils	2nd Layer Thickness at 0.01 lbs/in^2 mils	Appearance[b] of 2nd Layer	Exposure[c] Time, t_{15} min	Overall Thermal[d] Resistance, R_T m^2 sec C°/cal
100% Orlon serge (20)	156	37	wet	12.4	0.280
50% Orlon, 50% wool serge (28)	168	53	wet	12.5	0.275
100% wool serge (17)	178	64	damp	16.1	0.355
85% wool, 15% nylon shirting (F)	194	82	damp	15.0	0.325

a 1st layer 50/50 wool/cotton underwear, 3rd layer oxford jacket, 4th layer sateen shell.
b Visual appearance after completion of cooling run.
c The time taken for the chamois skin to drop to 15°C.
d Calculated using the Cold Wind Tunnel Equation (1).

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Table 4, Report 13

Moisture Distribution and
Thermal Resistance of Four Layer Cold Weather Assemblies,
Wind Velocity 11.7 mph, Initial Temp 30°C, Wind Tunnel Temp - 5°C

Serge in Fabric Assembly	Assembly Thickness (.01 lb/in^2)	Equilibration Time at 30°C	Moisture Gained by				Overall Thermal Resistance, R_T*
			Underwear	Serge	Oxford	Sateen	
	mils	min	%	%	%	%	m^2 sec C°/cal
Orlon	156	25	37	33	16	5	0.295
Orlon	152	40	37	42	31	10	0.285
Wettable Wool	165	25	33	27	18	5	0.330
Wettable Wool	167	40	30	34	29	7	0.310
Sheared Wool	160	25	40	30	8	4	0.300
Sheared Wool	166	40	42	34	11	7	0.295

*Calculated using equation (1)

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Table 5, Report 13

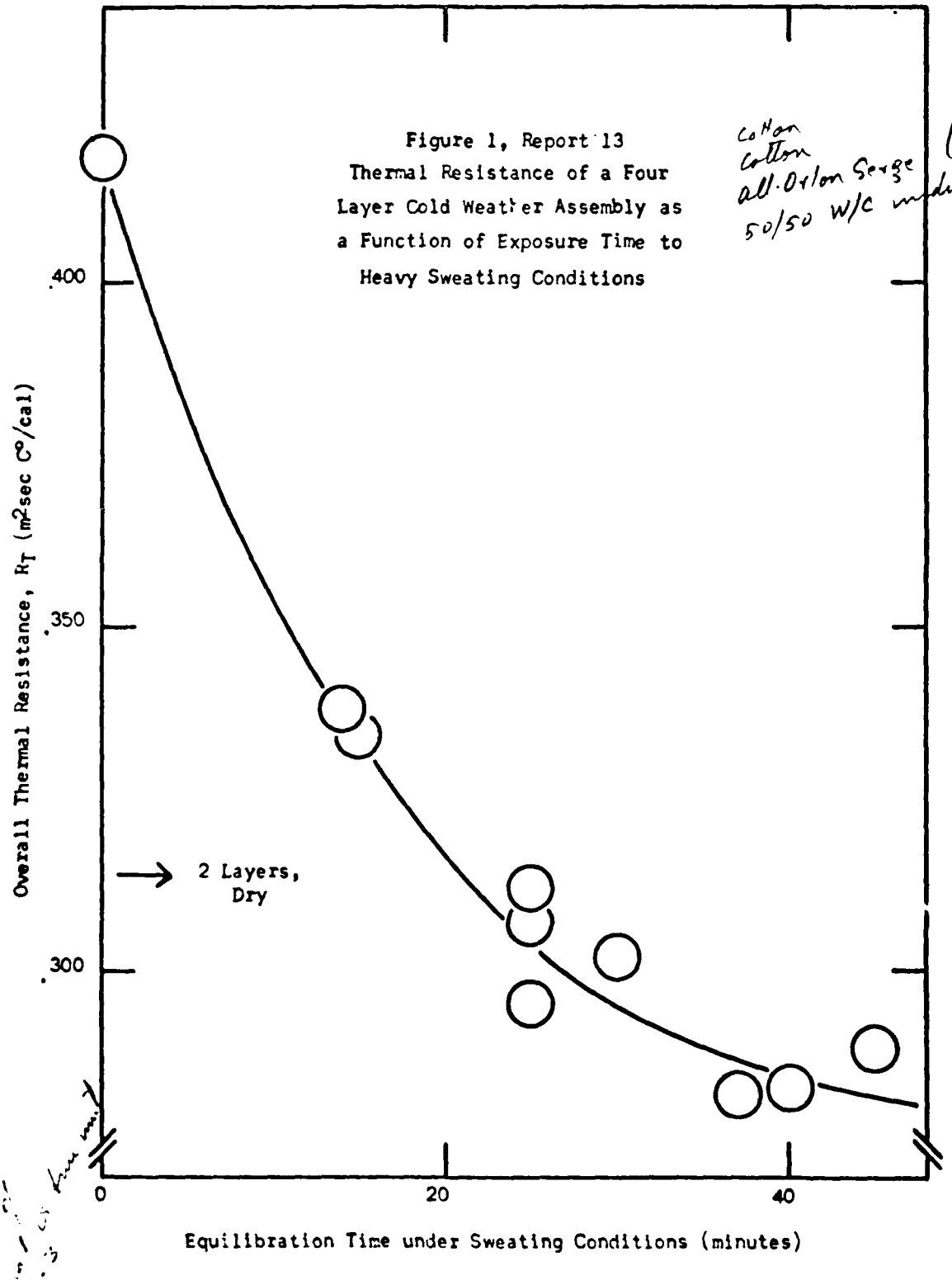
The Effect of Underwear and Serge Type on the Moisture Transfer and Thermal Resistance of Four Layer Cold Weather Assemblies, Wind Velocity 11.7 mph, Tunnel Temperature -5°, Cell Held at 30°C for 25 min.

Fabrics Used in Assembly		Moisture Gained By				Assembly Thickness at 0.01 lb/in^2	Overall Thermal Resistance, R_T[a]
Serge	Underwear	Underwear	Serge	Oxford	Sateen		
		%	%	%	%	mils	m^2 sec C°/cal
Sheared wool (17S)	nylon (62)	29	34	8	6	147	0.315
Orlon (20)	nylon (62)	32	33	24	6	137	0.285
Sheared wool (17S)	nylon[b] (65)	15	28	5	4	126	0.310
Orlon (20)	nylon[b] (65)	16	20	16	4	123	0.275

a Calculated using equation (1).
b Water repellant.

Figure 1, Report 13
Thermal Resistance of a Four Layer Cold Weather Assembly as a Function of Exposure Time to Heavy Sweating Conditions

CoHon Cotton All-Orlon Serge 50/50 W/C underwear (20)



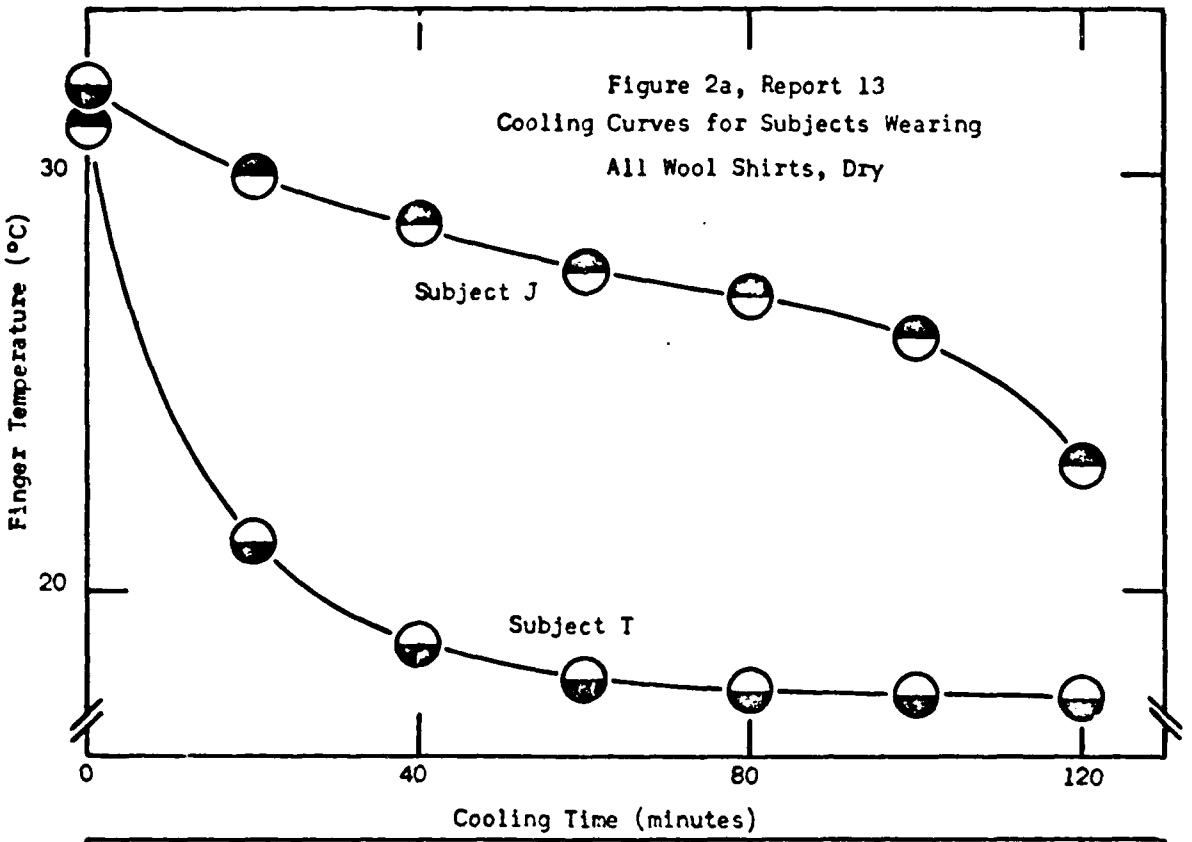


Figure 2a, Report 13
Cooling Curves for Subjects Wearing
All Wool Shirts, Dry

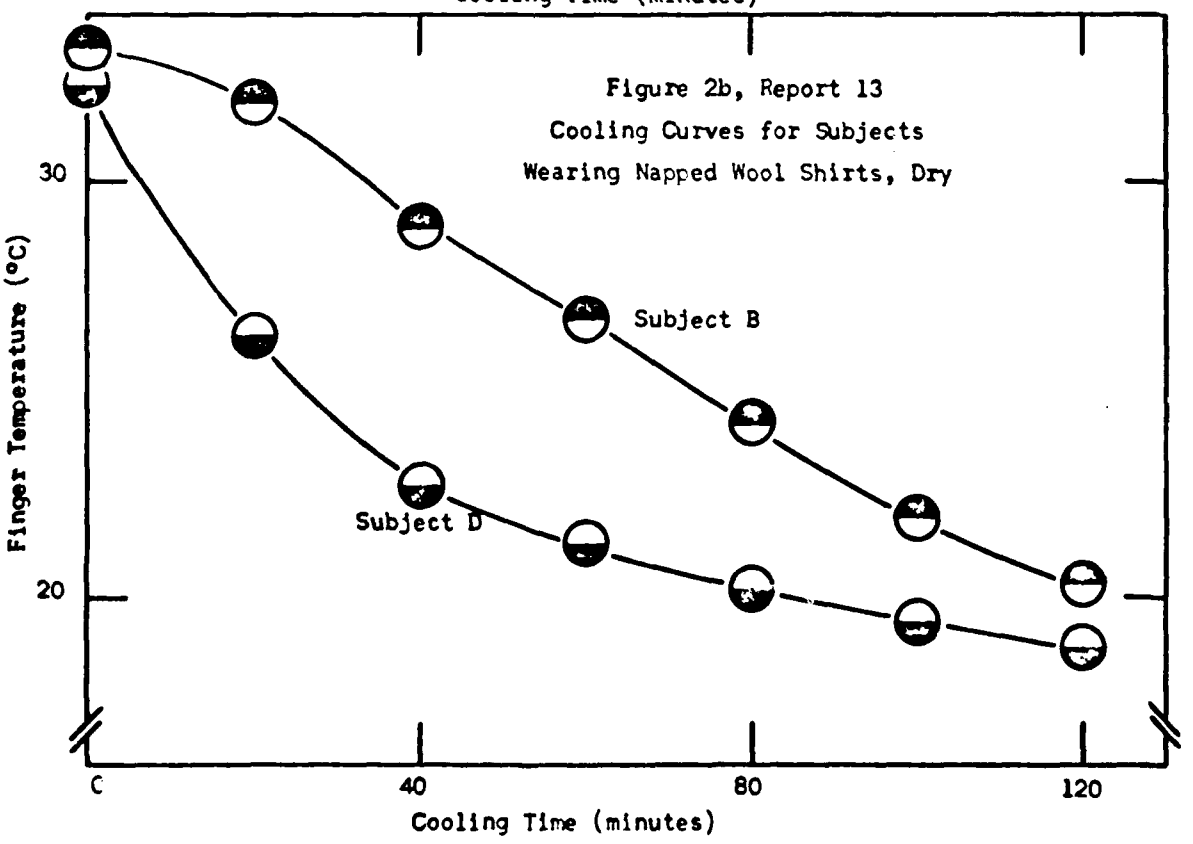


Figure 2b, Report 13
Cooling Curves for Subjects
Wearing Napped Wool Shirts, Dry

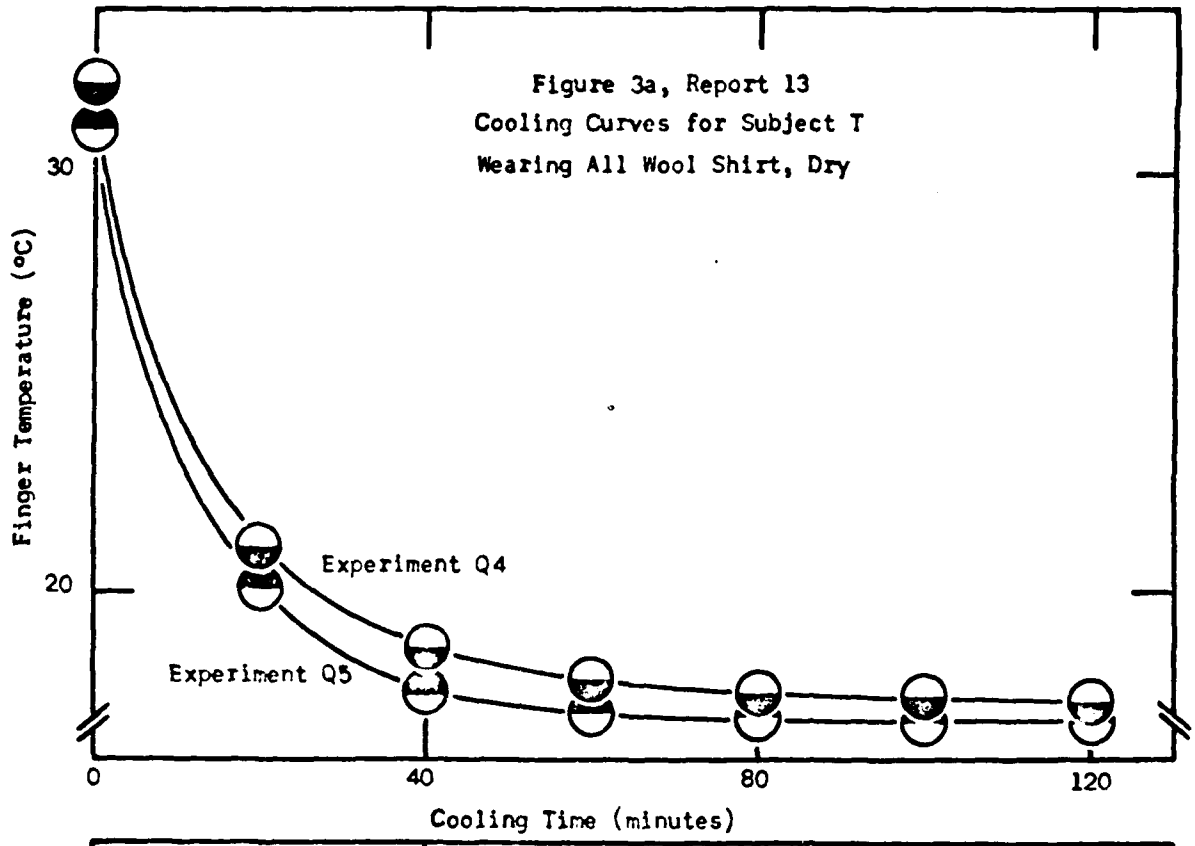


Figure 3a, Report 13
Cooling Curves for Subject T
Wearing All Wool Shirt, Dry

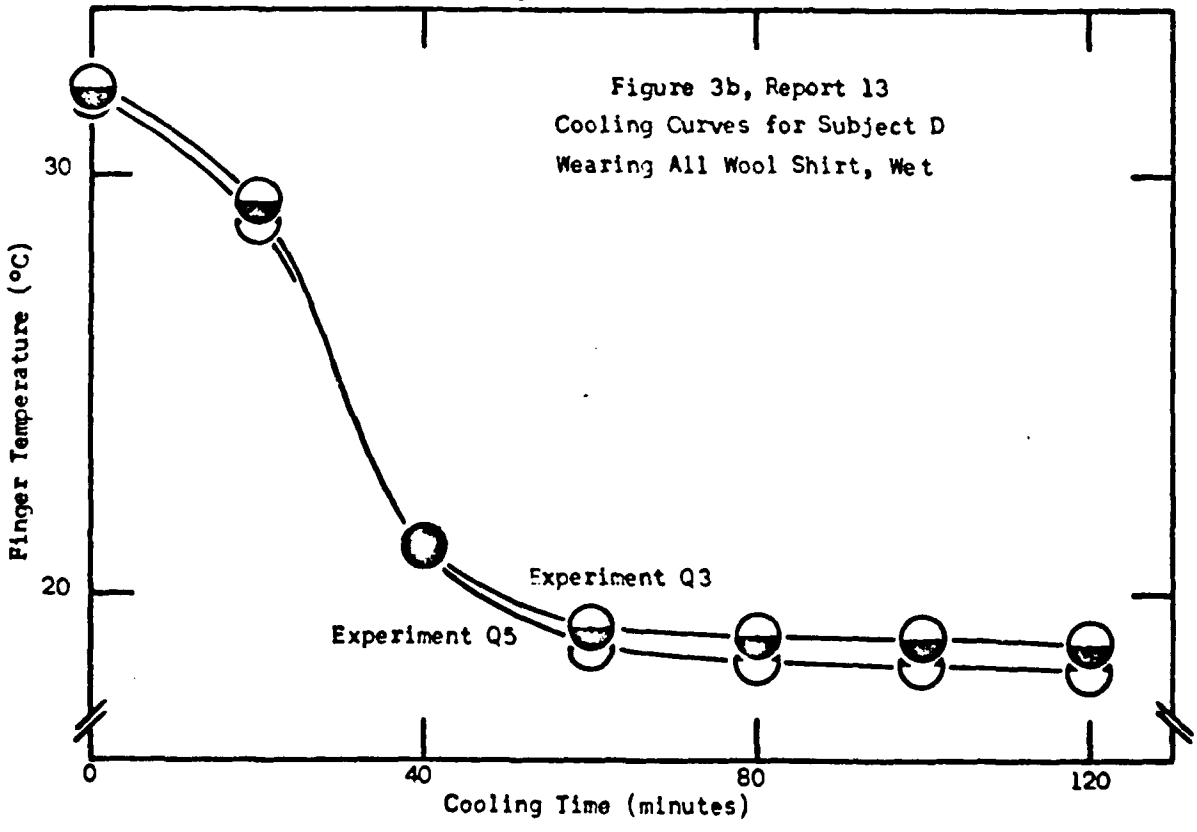


Figure 3b, Report 13
Cooling Curves for Subject D
Wearing All Wool Shirt, Wet

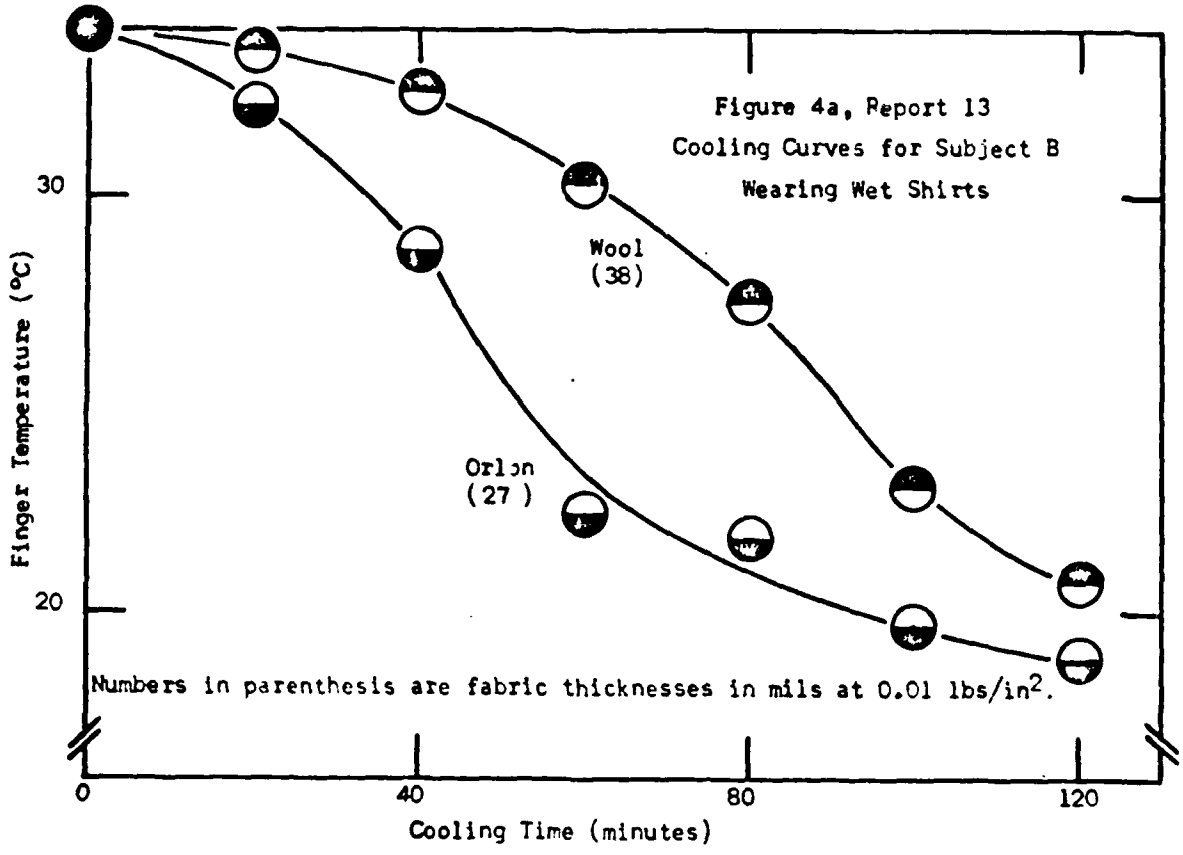


Figure 4a, Report 13
Cooling Curves for Subject B
Wearing Wet Shirts

Numbers in parenthesis are fabric thicknesses in mils at 0.01 lbs/in^2.

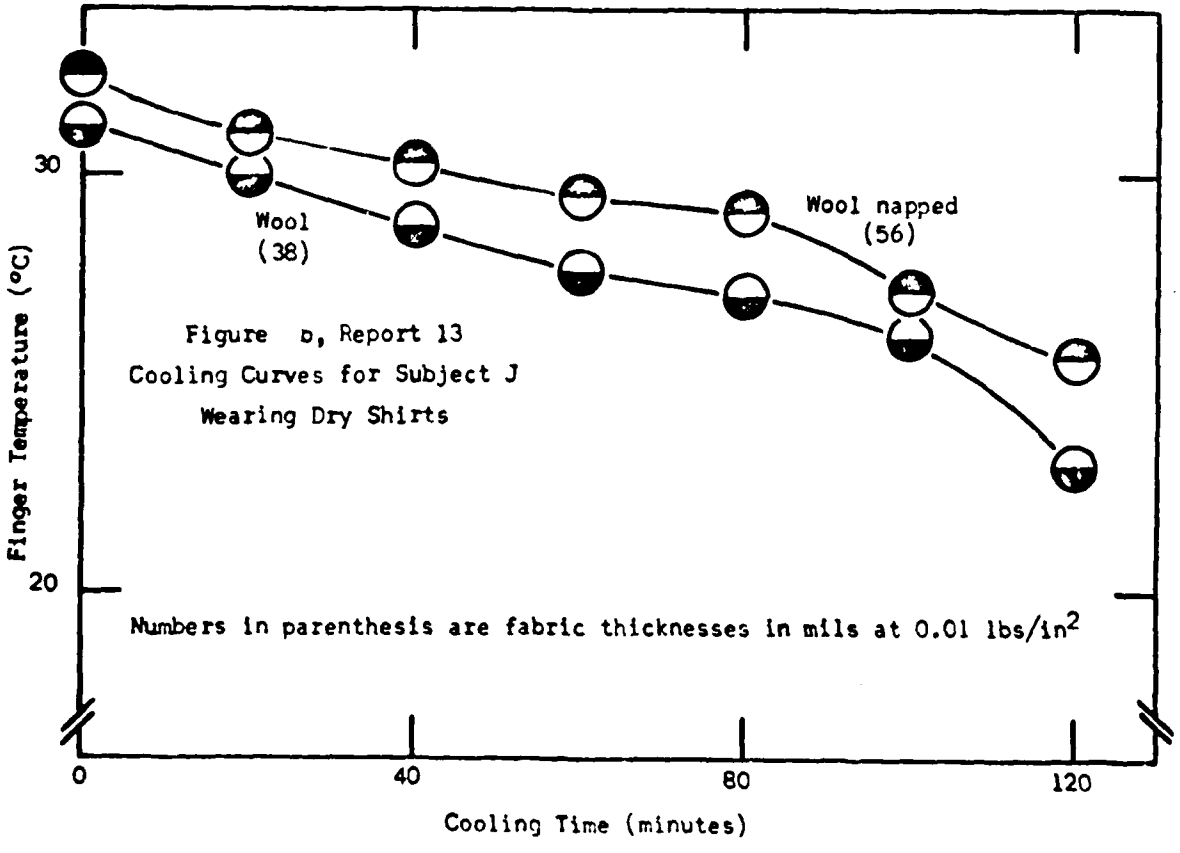


Figure b, Report 13
Cooling Curves for Subject J
Wearing Dry Shirts

Numbers in parenthesis are fabric thicknesses in mils at 0.01 lbs/in^2